The Mineralogy and Depositional Environment of the Wales Oil Shale

A Thesis

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By

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INTRODUCTION

The Wales Oil Shale Member of the North Horn Formation was deposited in a fresh water pond on a fluvial flood plain. Two distinct forms of lacustrine sedimentation are represented by an apparent change from aerobic to anaerobic conditions in the pond environment. The earlier phase produced a 3 m thick sequence of bioturbated oil shale with moderate amounts of diagenetic alteration; the later phase is represented by an 11 m thick sequence of well bedded and relatively unaltered oil shale.

The Wales Oil Shale is exposed near the eastern base of the Gunnison Plateau, approximately 230 km south of Salt Lake City, Utah (Figure 1). A section was described and sampled a few metres south of the road in T15S R2E SW¼ NE¼ of the Wales 7.5 min. quadrangle of the U.S. Geological Survey.

PREVIOUS STUDIES

Work on the Wales Oil Shale began in 1872 when Gilbert described and measured a section of the Wales Member. White (1882) described a molluscan fauna from what he refered to as the Wasatch Formation near Wales. Richardson (1906) discussed the coal in Sanpete County and the coal mine near Wales, which Clark (1912) also studied. The North Horn rocks were first described in detail by Spieker and Reeside in 1925, which they identified as the lower member of the Wasatch Formation. In 1946 Spieker raised the North Horn Formation to formational status and reported upper Cretaceous and Paleocene fossils in the type section.

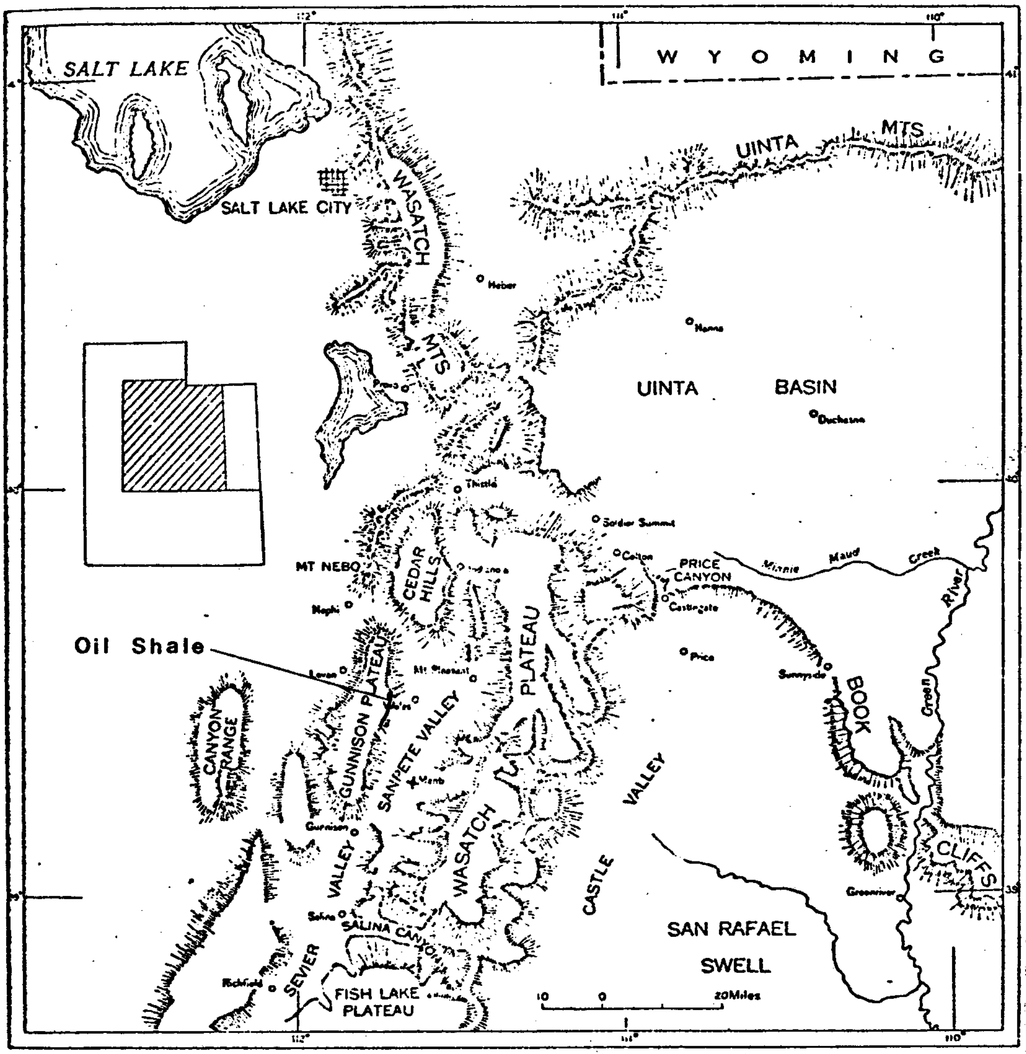


Figure 1. Index map of part of Utah, showing the location of the Wales Oil Shale. After Spieker (1946, p.119).

Peck and Reker (1948) reported on charophyta found near a coal seam behind Wales. Hunt (1950) studied the northern part of the Gunnison Plateau, mapping the coal unit north from Wales Canyon to where it pinches out near Kern Canyon. La Rocque (1956) described the Tertiary molluscan fauna of central Utah.

Birsa (1973), who described the North Horn Formation in detail, mapped the formation from the south end of the Gunnison Plateau to Wales Canyon, an area across which facies abruptly change. He also mapped the coal south of Wales Canyon to where it pinches out just south of Petes Canyon.

Fugitt (1976) studied the paleomagnetics of the oil shale and reported a magnetic reversal in the lower part. Sauer (1977) applied a trace element study of the oil shale toward an interpretation of the depositional environment. Many other reports on the Sanpete area are available, mostly in the form of unpublished theses and dissertations at the Ohio State University. A list of these may be found in Collinson (1968).

Most previous work done on oil shale involves the Green River Formation of Colorado, Utah, and Wyoming. Much of this was conducted by W.H. Bradley (1925, 1926, 1929, 1931, 1948, 1966, 1970, 1973, and Sears and Bradley, 1924). Useful descriptions of the Green River Oil Shale and its mineralogy as used for determining environment of deposition are found in Tank (1972) and Eugster and Surdam (1973).

I would like to extend my gratitude to professors James W. Collinson, Gunter Faure, James M. Schopf, Kenneth O. Stanley, and Rodney T. Tettenhorst for their assistance and for use of their equipment. Jeffery H. Franklin gave valuable assistance with the scanning electron microscope. I would also like to thank graduate students Lon McCullough and Neil Wells for providing the samples and for valuable discussions, and James Sauer for his assistance with the work.

GEOLOGIC SETTING

The stratigraphic sequence in the Sanpete area comprises rocks ranging from late Jurassic to Recent. The Cretaceous-Tertiary North Horn Formation, which consists of conglomerate, sandstone, shale and limestone, conformably overlies the massive sandstone and locally coarse conglomerate of the Cretaceous Price River Formation. Where the Price River Formation is absent, the North Horn overlies older Cretaceous and Jurassic rocks unconformably.

The North Horn Formation grades upward into the lacustrine limestone of the Tertiary Flagstaff Formation. At a few localities, the contact between the North Horn and the Flagstaff Formations is an unconformity (Birsa, 1973, p.48).

The Sanpete area has been described as the transition between the Colorado Plateau and the Basin and Range geologic provinces (Spieker, 1946) and for this reason is a region of complex structure. The major structures in the area include an anticline in Sanpete Valley, the Wasatch monocline along the west side of the Wasatch Plateau to the east, and a syncline beneath the Gunnison Plateau to the west.

NORTH HORN FORMATION

The North Horn Formation, as defined by Spieker (1946, p.133), consists primarily of lacustrine and fluvial deposits, and is present through much of central Utah (Hunt, 1950, p.73). Birsa (1973, p.44) reported thickness variation from 0-1128 metres along the east side of the Gunnison Plateau.

Spieker divided the North Horn Formation into four members in its type section on the Wasatch Plateau. His division involved two lacustrine and two 'floodplain' facies (Spieker, 1946, p.133). Although Spieker's division is applicable over much of central Utah, it is not applicable on the Gunnison Plateau where abrupt facies changes are the rule. In answer to this problem, Hunt divided the North Horn Formation in Wales Canyon into three units: a lower unit of variegated fine to coarse clastics, a middle member composed of the Wales Coal and Oil Shale, and an upper member of limestone and shale (Hunt, 1950, p.74).

Birsa recognised four major facies along the Gunnison front. These include a coarse-grained clastic facies, a medium-grained clastic facies, a fine-grained and carbonate facies, a coarse- to medium-grained transitional facies (Birsa, 1973, p.65). The Wales Oil Shale Member belongs to the fine-grained clastic and carbonate facies. Birsa (1973, p.84) characterized the fine-grained clastic and carbonate facies as resulting from a low energy environment. The majority of this facies is composed of variegated shale, mudstone and limestone with sandstone bodies interbedded with the limestone and shale (Birsa, 1973, p.84). Birsa interpreted the lower part as the result of fluvio-lacustrine deposition and the upper part as the result of lacustrine sedimentation.

AGE

Assigning an age to the North Horn Formation has been a problem. Early studies of molluscan fauna placed its age as Eocene (White, 1886, p.10). Later studies revealed ceratopsian remains in the lower part of the formation and mammalian bones in the upper part indicating that the North Horn Formation straddled the Cretaceous-Tertiary boundary at the type section (Spieker, 1946, p.134).

In Peck and Reker's (1948, p.85) description of charophyta from strata near the coal west of Wales, they assigned the flora an Eocene and Oligocene age, but this younger age assignment may be related to the failure of the U.S. Geological Survey to adopt the Paleocene as a valid division of the Tertiary until recently.

During the 1976 field season a jaw bone of a condolarth, a Paleocene mammal, was found in the oil shale strata (identified by J.A. Lillegraven).

WALES OIL SHALE

The Wales Oil Shale consists of coal and kerogenous limestone and shale. The Wales Coal described by Richardson (1906) and other early workers is included in the oil shale member. The type section of the oil shale is located 2.8 km west of Wales, where the oil shale is approximately 14 m thick, thinning to the north and south. In this area the oil shale is prominent, its resistant beds forming west dipping cuestas. The oil shale is limited to the eastern face of the Gunnison Plateau by an abrupt facies change within the North Horn Formation.

Fossils within the oil shale sequence include conchostracans, charophytes, mollusks, and condolarth remains. The charophytes (Plate 1) have been identified as <u>Aclistochara compressa</u> (Peck and Reker, 1948). These calcareous algae, which are present in all but the lowest metre of strata, indicate that the kerogen may be of algal origin. Bivalves and gastropods are common in most of the beds. The bivalve shells have a prismatic structure (Plate 2), whereas the gastropods are all recrystallized and filled by secondary spar. Fish tooth and bone material (Plates 3 & 4) is also present in several samples. These fossils suggest that the lake in which the oil shale was deposited was probably fresh water.

MINERALOGY

Minerals in the oil shale include calcite, aragonite, pyrite, dolomite, clay minerals, and minor amounts of barite,

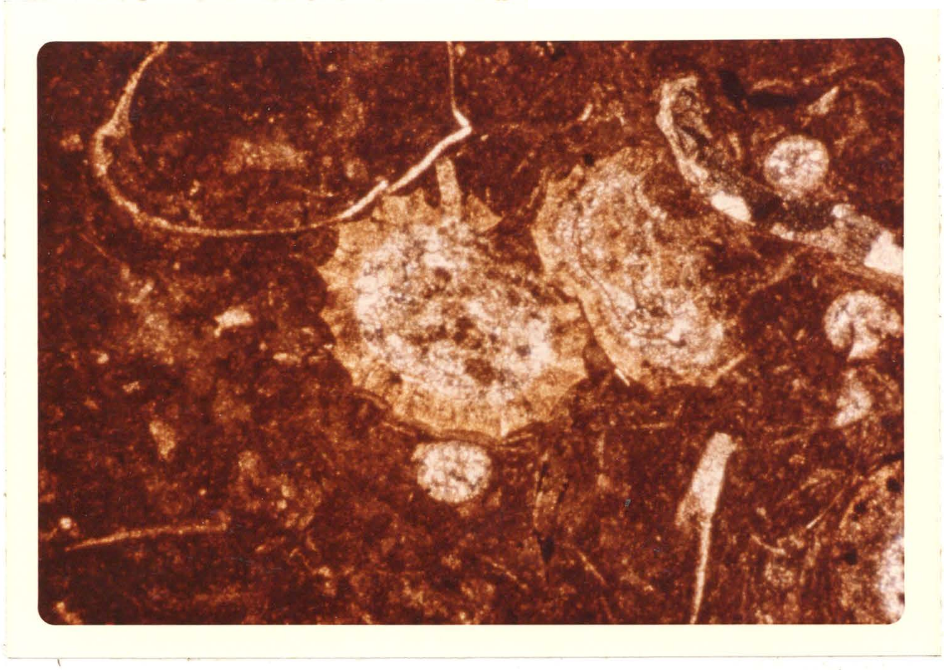


PLATE 1. Photomicrograph: chara, note lack of bedding. Sample WCC-8, crossed nicols, 40x, print represents 2 x 3 mm.

PLATE 2. Photomicrograph: prismatic bivalve shell with secondary barite filling. Sample WCC-21, crossed nicols, 40x, print represents 2 x 3 mm.

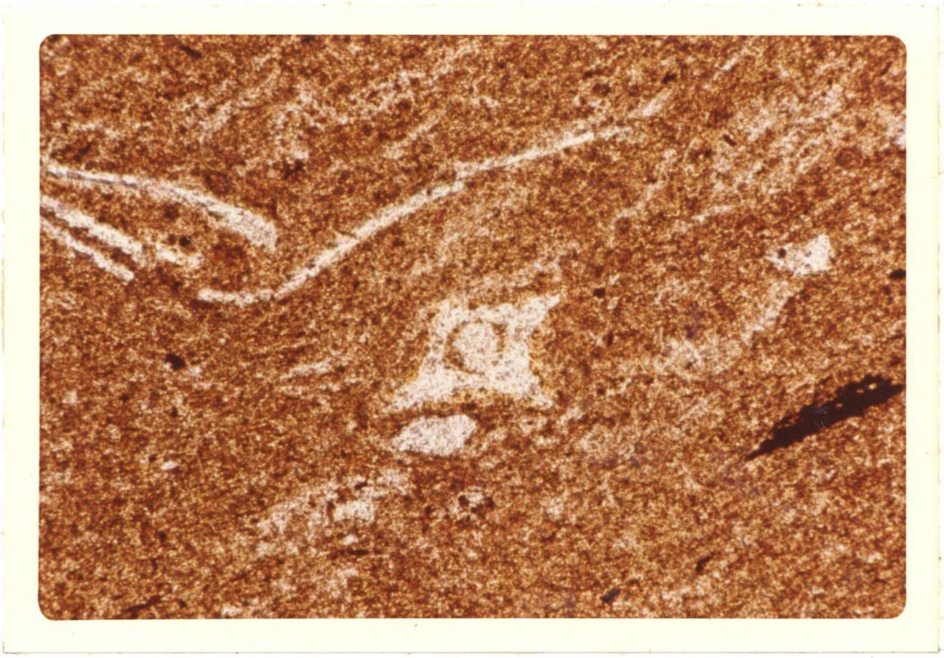


PLATE 3. Photomicrograph: phosphate bone material. Sample WCC-9, P.P.L., 100x, print represents 0.8 x 1.2 mm.

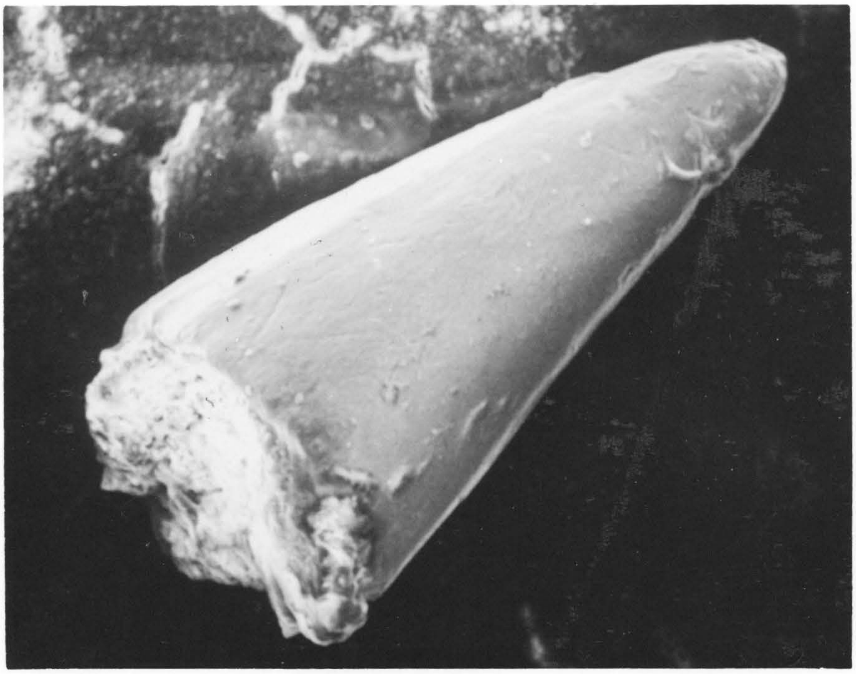


PLATE 4. Scanning electron photomicrograph: fish tooth. Sample WCC-20, 200x, print represents 0.0055 x 0.0045 mm.

plagioclase feldspar and zircon. The mineralogy was determined by X-Ray diffraction and optical methods which are discussed in Appendix 1.

Calcite appears to be the dominant mineral in all but the coal samples (Tables 1 & 2). Primary calcite is present as fossil fragments and micrite. Secondary calcite, which is present as spar void fillings and as the product of aragonite shell inversion, is especially evident in the bioturbated samples (Plate 5). The small amount of calcite void filling in the bedded samples must have been penecontemporaneous; otherwise compaction would have crushed the unfilled shells. Ferroan calcite occurs as void fillings in some of the bioturbated samples.

Aragonite in the form of prismatic bivalve shells is found in the samples where rapid compaction prevented ground water infiltration, and thus the inversion of the aragonite. In the few samples in which aragonite shell material and sparry calcite coexist, it is generally believed that the spar was brought in by solutions from elsewhere instead of being the product of direct inversion of aragonite (Bathurst, 1975, p.442). All of the bioturbated samples lack aragonite, probably because burrowing increased the permeability of the sediments, thus allowing the diagenesis to take place.

Diagenesis by ground water action is also responsible for minor amounts of dolomite present in the bioturbated samples. Ferroan dolomite occurs as gastropod void filling

TABLE 1

X-Ray Data

MINERAL	SAMPLE NUMBER																								
	1	3b	4a	5	6	7b	8	9	10	11	12	13	14	15	16	17	18	20	21	22	23	24	25	27	28
Calcite	A	C	C	S	C	C	A	C	A	A	A	A	S	S	S	S	C	S	C	C	A	S	S	C	C
Quartz	A	A	C	C	A	S	S	S	S	S	S	S	S	S	S	A	S	S	S	S	S	C	S	S	S
Aragonite	-	-	-	-	-	-	-	-	-	-	-	S	-	-	S	-	-	-	-	S	-	-	-	-	-
Dolomite	S	S	S	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrite	-	-	-	-	S	-	-	-	-	-	S	S	S	-	S	-	-	-	-	S	-	-	-	-	-
Barite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	S	S	-	-	-	-	-

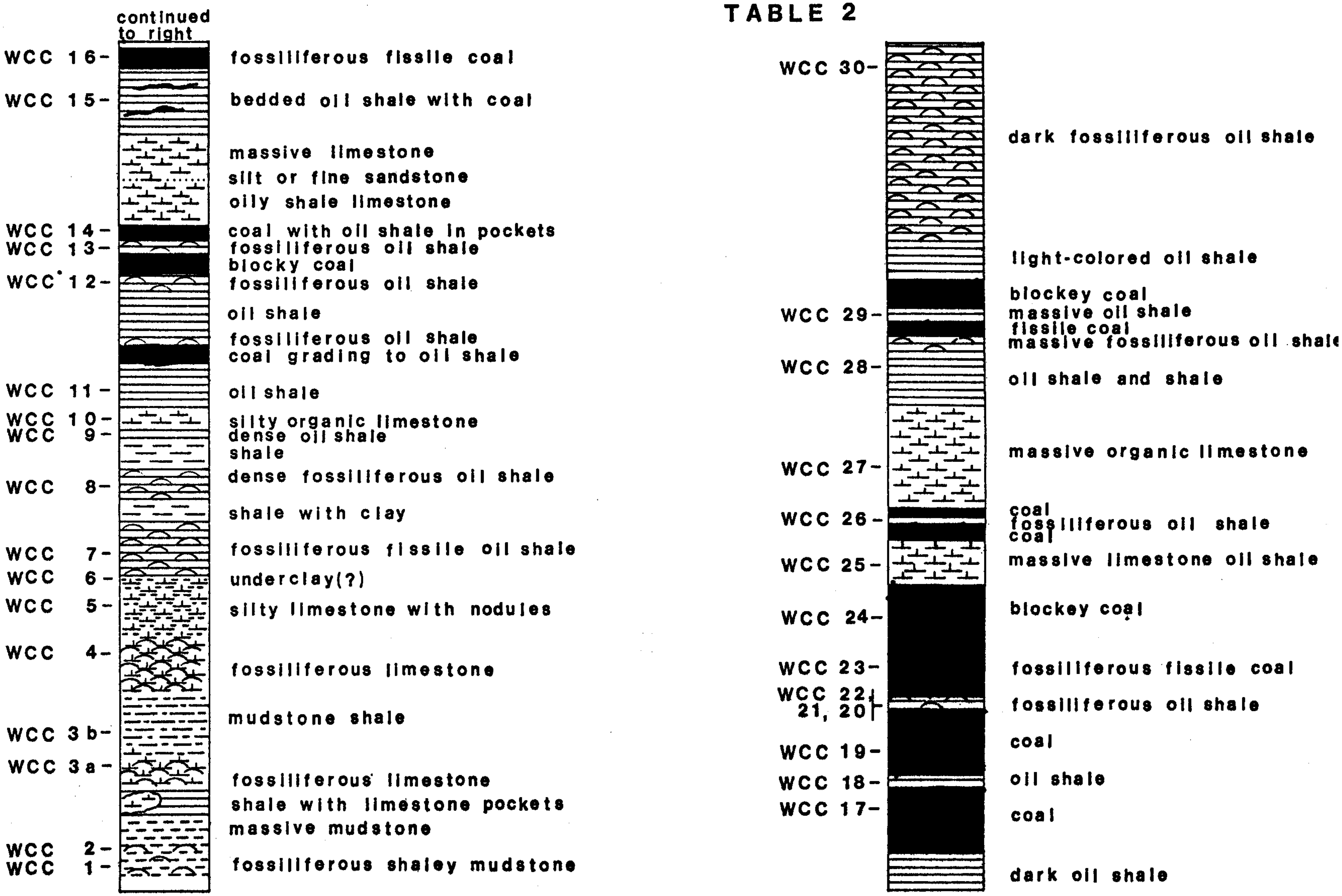
A = Abundant

C = Common

- = Absent

S = Sparse

TABLE 2



Stratigraphic relation of samples with field descriptions

[from Sauer, 1977, p. 30]

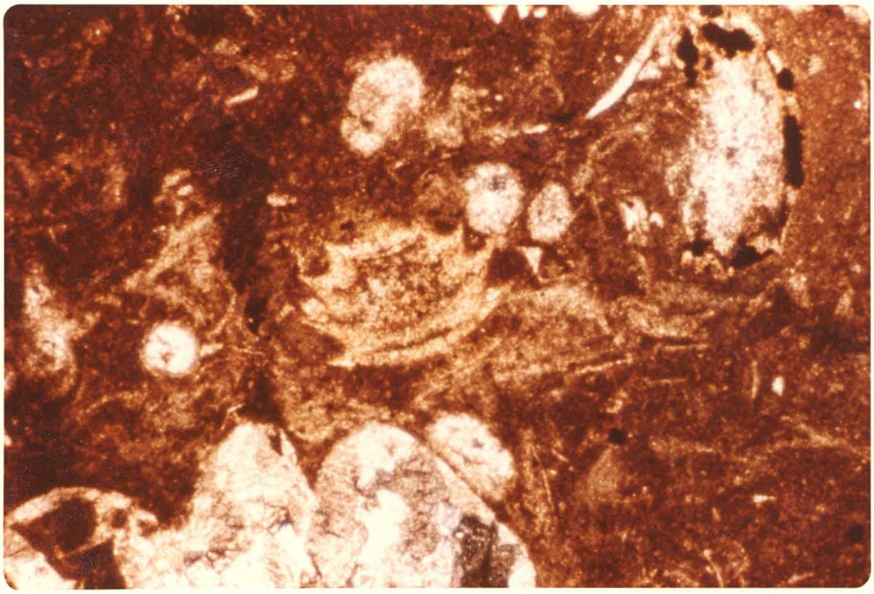


PLATE 5. Photomicrograph: chara and gastropod, note secondary spar filling and lack of bedding. Sample WCC-8, crossed nicols, 40x print represents 2 x 3 mm.

in the lowest of the bioturbated samples.

Euhedral grains of pyrite are present in most of the samples from the sequence collected above sample 9, but in only a few cases is the concentration great enough to be detected by the diffractometer. Well-rounded quartz grains are visible in most of the samples as detrital grains (Table 3).

The clay mineralogy of the oil shale is uniform with smectite, illite, kaolinite, and lesser amounts of chlorite, and mixed layer clays. The wide variety and uniform distribution of the clays suggest that they are detrital (Tank, 1972, p.306).

Detrital grains of zircon and weathered plagioclase feldspar occur in trace amounts in most of the samples. The plagioclase grains are partially replaced with sericite, and a few show epitaxial calcite overgrowths.

The presence of barite void fillings (Plate 2) in three samples (20, 21, & 22) suggest a high concentration of barium in the ground water during the deposition of these samples (Ham and Merritt, 1944, p.20). The source area for the barium is not presently known.

The organic material in the Wales Oil Shale occurs in two forms, a ubiquitous form which is dark-brown to black and very fine-grained, and a less common form which is birefringent and pleochroic in red to red-brown (Plate 6). The black material was probably derived from vascular plants, whereas the pleochroic material, which forms stringers

TABLE 3

Optical Data

CONSTITUENT	SAMPLE NUMBER																			
	1	3b	5	6	7b	8	9	9b	11	12	13	15	18	20	21	22	25	27	28	29
Red organic matter	-	-	S	S	C	-	S	S	-	C	A	A	S	A	S	S	S	S	C	S
Bioturbation	A	A	C	A	C	A	-	-	-	-	-	-	-	-	-	-	S	-	A	A
Charophyta	-	-	-	-	-	A	-	C	A	S	S	S	-	-	-	-	S	C	S	S
Bivalves	P	P	P	-	-	-	-	-	-	-	-	P	P	P	P	P	-	-	P	-
Conchostracans	P	-	-	-	-	-	-	P	P	P	P	P	P	P	P	P	P	-	P	-
Gastropods	-	-	-	-	-	P	-	P	P	P	P	-	-	P	P	P	P	P	P	-
Quartz	C	C	A	A	S	S	S	S	S	S	S	S	S	S	S	A	C	S	C	S
Phosphate+	-	-	-	-	-	-	P	-	-	-	-	-	-	P	P	-	-	-	-	-

A = Abundant

C = Common

S = Sparse

P = Present but abundance not determined

- = Absent

+ phosphate occured as bones and teeth

through many of the samples, was probably derived from algal hydrocarbons and fatty acids (Cane, 1976, p.46).

INTERPRETATIONS

The Wales Oil Shale shows two distinct fresh water lacustrine regimes. Samples 1-9 and 28-29 are bioturbated and moderately altered by diagenesis, whereas samples 10-27 are well bedded, compacted, and unaltered diagenetically.

The presence of fish and fresh-water bivalves, gastropods, chara, and conchostracans, along with the lack of evaporate minerals, indicate that the lake was fresh. The lack of mudflat facies and the fairly uniform lithology in the area of study suggest that the lake did not undergo drastic changes in water depth. These also suggest that there was not much seasonal change in water level or clastic supply as the lake showed no sign of desiccation, oxidation or seasonal varves.

In samples 1-9, evidence of bioturbation, the absence of pyrite, and the low organic content as determined by color and density, indicate aerobic conditions when these lower samples were deposited. The bivalves and gastropods may have contributed to the bioturbation, which increased the premeability of the sediments, and thus permitted ground water circulation to contribute to the diagenesis. Diagenesis in these samples is represented by dolomitization, secondary spar fillings, and inversion of aragonitic shell material.

Samples 10-27 are bedded and highly compacted with differential compaction around fossil fragments. There is

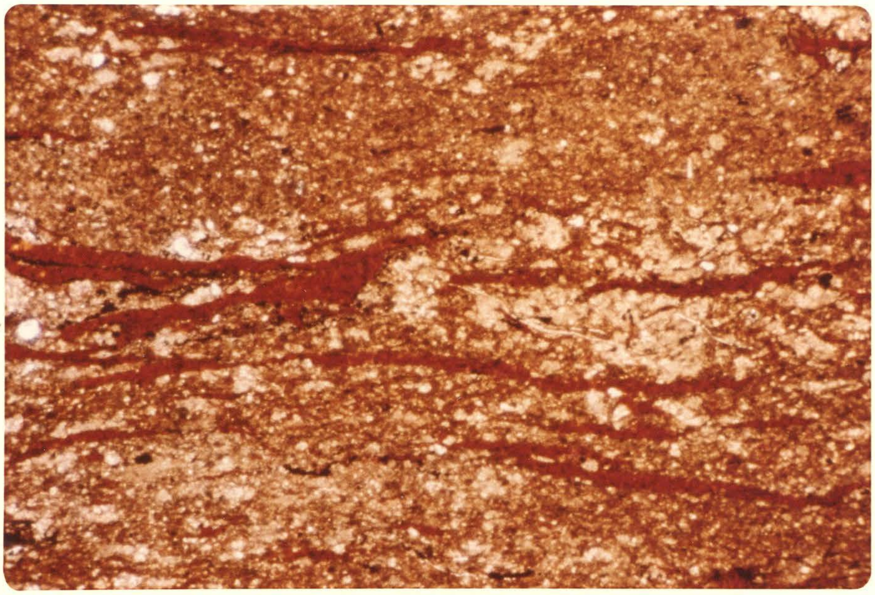


PLATE 6. Photomicrograph: red organic stringers and dispersed black organic matter. Sample WCC-7b, P.P.L., 40x, print represents 2 x 3 mm.

little evidence of diagenesis. The general lack of benthonic forms, the high amount of organic matter, and the presence of pyrite suggest that these samples were deposited in a reducing environment. The small amount of diagenesis present, in the form of spar void fillings, was penecontemporaneous, because otherwise open shells would have been crushed by compaction. After compaction the lack of permeability would probably have prevented the circulation of solutions necessary for diagenesis. As the algal material was being deposited, the circulation of carbonate-rich ground water resulted in the precipitation of the spar void fillings. Soon after deposition of the oil shale and the formation of the spar, but before the aragonite could invert, the sediment underwent compaction. Gastropods and chara that had been filled with spar withstood compaction, whereas the unfilled fossils were crushed (Plate 7).

RECOMMENDATIONS FOR FURTHER STUDY

It is clear that much additional work will be required before the depositional environment of the Wales Oil Shale is completely understood. More sections of the oil shale and neighboring rocks need to be described and sampled, and the entire area of the outcrop will have to be carefully mapped with special attention to differing lithologies within the oil shale. Stratigraphic control must be obtained by mapping particular units within the Wales Member, if laboratory work is to be relevant.

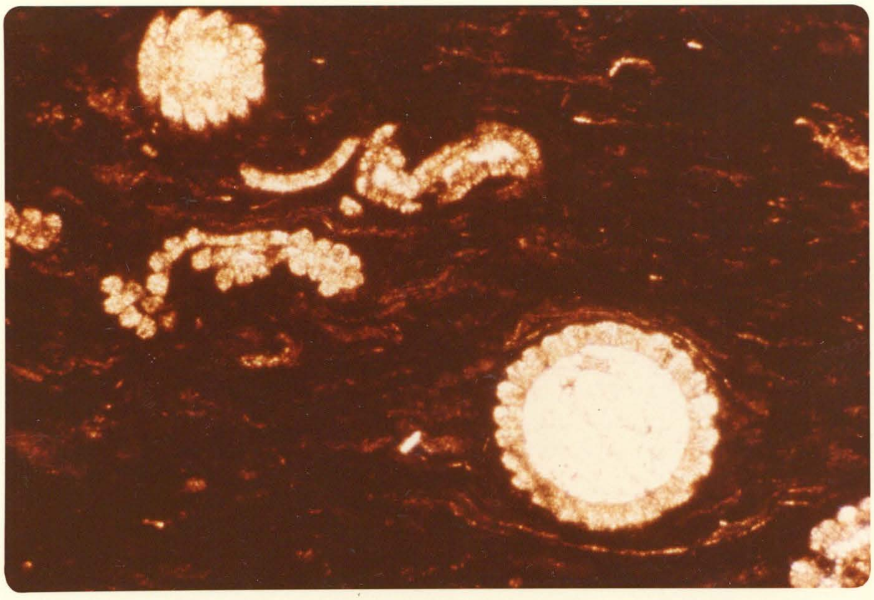


PLATE 7. Photomicrograph: chara, note contorted bedding around chara and crushing of unfilled chara. Sample WCC-11, P.P.L., 40x, print represents 2 x 3 mm.

Organic geochemistry studies are essential for the understanding of the lake chemistry and the chemistry of the organic sediments. A palynologic study of the oil shale would be very helpful in determining the paleoclimate of the area.

Questions that remain include the location of the source area for the water, the average temprature and rainfall, the length of duration of the lake, and the environmental changes that occurred during the lake's existance.

APPENDIX 1

SAMPLE PREPARATION

Standard

Acetate peels, thin and polished sections were prepared using standard methods. A set of acetate peels was stained with Alizarin Red-S and Potassium Ferricyanide in order to note local concentrations of dolomite, ferroan dolomite, and ferroan calcite. This staining proved to be unsucessful in most cases as the high amount of organic matter in the rocks prevented the stain from 'taking' properly.

The peels, thin and polished sections were then studied microscopically to determine the fabric, fossil constituents, and mineralogy of the oil shale.

X-Ray

The samples were prepared for X-Ray analysis by first removing a representative chip from each hand sample. The chip was hand pulverized in a motar and pestle, taking care not to overpulverize, which would cause the calcite to invert to aragonite. Approximately 2 g of the powder was then mounted on a glass slide in a water slurry mount. The remaining powder was oxidized in a 10% hydrogen peroxide solution to remove the organic matter which would interfere with the clay peaks. After oxidizing was complete, two types of clay mounts were made. The first method involved dispersing the residue in a solution of 10% Calgon and mounting the slurry on a glass slide. The second method, which proved to give better results, involved pressing 3 g of residue into a pellet which was then x-rayed.

The samples were studied on a General Electric model 11GN1 X-Ray Diffraction unit using nickel filtered copper radiation (Cu_k) at 45 KVP and 15 ma. The unoxidized mounts were scanned from 18° to 50° 2θ at 2° 2θ per minute with a 1° sollar slit and a 0.1° receiving slit. The oxidized samples were scanned for clay minerals from 3° to 15° 2θ using the same settings as the unoxidized samples.

The patterns were then compared to standard patterns (Joint Committee on Powder Diffraction Standards, 1971, and Chao, 1969) to determine the mineralogy. The clay peaks were also checked against patterns of untreated, glycolated, and heated clay minerals (Carroll, 1970, Grim, 1968, and Weaver, 1958).

An analytical peak was then used as a crude indicator of abundance of a particular mineral. This abundance was used to compare the amount of a certain mineral in one sample to the amount of that same mineral in another sample. The results of the x-ray study were compared to the optical results, and the relations were noted.

APPENDIX 2

MEASURED SECTION OF THE WALES OIL SHALE

The section was measured and sampled a few metres south of the road in T15S R2E SW¼ NE¼ of the Wales 7.5 min. quadrangle of the U.S. Geological Survey. The section is well exposed in Wales Canyon, 2.8 km west of Wales. The underlined numbers are sample numbers.

		Centimetres
47.	Dark slightly fossiliferous oil-rich shale <u>WCC-30</u>.	111.8
46.	Dark fossiliferous oil shale.	86.4
45.	Light colored oil shale, unfossiliferous.	30.5
44.	Blocky thinly banded coal; upper surface of coal is fluted or channel cut.	15.2
43.	Nodular black massive poorly fossiliferous oil shale <u>WCC-29</u>.	17.8
42.	Shale with coal.	5.1
41.	Massive fossiliferous oil shale <u>WCC-28</u>.	20.3
40.	Very fissile shale, more shaley than 1, stringers of oil shale 5-12.5 cm wide.	43.2
39.	Massive organic limestone <u>WCC-27</u>.	81.3
38.	Coal.	3.8
37.	Fossiliferous oil shale separated by coal stringers <u>WCC-26</u>.	10.2
36.	Coal.	12.7
35.	Limestone-oil shale massive, unfossiliferous <u>WCC-25</u>.	38.1
34.	Blocky coal <u>WCC-24</u> with coaly shale in middle.	7.6
33.	Coal, fissile and fossiliferous <u>WCC-23</u>.	88.9
32.	Oil shale with fossil fragments <u>WCC-20-22</u>.	12.7
31.	Coal <u>WCC-19</u>.	45.7
30.	Oil shale sparcely fossiliferous <u>WCC-19</u>.	17.8
29.	Coal <u>WCC-18</u>.	48.3

28.	Dark oil shale.	35.6
27.	Thinly-bedded, highly fossiliferous coaly shale WCC-16.	7.6
26.	Medium-bedded oil shale separated by 1-2 cm coals; somewhat fissile shale WCC-15 from middle.	58.4
25.	Limestone-oily shale massive.	40.6
24.	Siltstone of fine sandstone, a continuous layer.	2.5
23.	Limestone as 25, but laminated.	38.1
22.	Coal with abundantly fossiliferous oil shale pocket WCC-14.	5.1
21.	Abundantly fossiliferous oil shale WCC-13.	16.5
20.	Blocky coal.	10.2
19.	Oil shale with very small crushed shells WCC-12.	22.9
18.	Oil shale similar to 19, sparcely fossiliferous.	33.0
17.	Dense fossiliferous oil shale.	5.1
16.	Coal, grades upward into oil shale 17.	11.4
15.	Oil shale WCC-11.	47.0
14.	Silty oily organic limestone WCC-10.	7.6
13.	Unfossiliferous oil shale, dense WCC-9a-b.	15.2
12.	Shale in pockets 35 cm long, coaly shale.	11.4
11.	Oil shale with snail fragments WCC-8.	35.6
10.	Brown shale variable in thickness; not well lithified, locally clay.	7.6
9.	Oil shale with clams and snails, fissle WCC-7a-d, shale in middle, thickness of shale varies, maybe as great as 12.5 cm.	58.4
8.	Calcareous shaley limestone with snail fragments WCC-5, underclay (?) WCC-6, nodules of limestone with fossil fragments in silty shale, each nodule separated but several are in stringers chronologically similar (? puddles).	45.7
7.	Argillaceous limestone with clams and snails, shells commonly crushed WCC-4a-d.	40.6

6.	Limestone with shell fragments.	20.3
5.	Silty cohesive mudstone-shale, concentric lines of brown mudstone WCC-3b.	30.5
4.	Same as 6, but less cohesive and lithified	30.5
3.	Shale with limestone lenses, many snails.	25.4
2.	Light olive-gray, fissle mudstone with some shell fragments WCC-1-2.	20.3
1.	Massive mudstone similar to 2, but not as cohesive.	22.9

Total thickness of the Wales Oil Shale Member of the North Horn Formation: 1401.4 cm

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